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Structural Work Duration Estimation and Analysis of Tower-Type Residential Construction Project

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Abstract In order to shorten construction duration in high-rise project, construction company tried to make various system method toward simplifying construction method and shortening construction duration. Though high-rise tower-type residential project are growing, there are few case study. Then, the data for preliminary schedule planning in high-rise tower-type residential project are rare. This purpose of research shows construction method in structural work in high-rise tower-type residential project, suggests schedule planning in structural work through case studies. The structural work in high-rise tower-type residential project was divided 1) completion of form in lower part and 2) the typical floor under penthouse. The statistical analysis were done in two parts, the data from analysis were used in simulation. Finally, researcher confirmed the difference between real construction duration and the figure from simulation. The results shows that the more construction duration is long, the less ACS's cost is low. It means the effectiveness is increasing in ACS, if the floor number is high.

Keywords: Form, Structural Work, Guide-rail System, Auto-climbing System, Simulation

1. INTRODUCTION

High-rise residential projects have been growing recently due to increased land price and enhanced life cycle, thus, the length of construction has increased. Likewise, the duration of proper construction and the baseline for the schedule are needed to ensure effective schedule management (Ji and Hyun, 2012). In order to shorten the duration of construction for high-rise projects, a construction company tried to introduce various system methods toward simplifying construction phases and shortening its duration (Han et al., 2004). Because tower-type residential projects are quite high and involve repeated processes, there is a need to minimize the cycle time per floor, such as TACT (Sim et al., 2009). Though high-rise, tower-type residential projects are growing, there have been few case studies. Thus, the data for preliminary schedule planning in high-rise, tower-type residential projects are rare.

The purpose of this research is to show the construction methods in structural work involved in high-rise, tower-type residential projects, and to suggest schedule planning in structural work through case studies.

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The research was performed as follows:

First, the structural work process of a residential project was analyzed, and the schedule planning of existing structural work was investigated.

In order to distinguish the existing structural work of a residential project, it was analyzed that the main construction methods in high-rise, tower-type residential projects were aimed at shortening construction time. Next, the construction methods were analyzed through a case study, wherein the difference between schedule planning and actual construction duration were investigated. Then, the research suggested the estimating method of construction duration in high-rise, tower-type residential projects.

The structural work in high-rise, tower-type residential projects was divided into: 1) completion of form in the lower part, and 2) the typical floor under the penthouse. The statistical analysis was done in two parts, with the data from the analysis used in simulation. Finally, the researcher confirmed the difference between the actual construction duration and the simulated figure. Because of variation in the design, the lower part of the residential project, the underground frame, and the penthouse were excluded in this research.

2. THE SCHEDULE MECHANISM OF TYPICAL FLOOR STRUCTURAL WORK

Concrete curing, form remaining period, and worker planning are major influences on construction duration (Bang et al., 2001). In order to define the logical influence to construction duration, the schedule mechanism for a typical floor formwork should be adopted. Then, in this chapter, activities are abstracted, while the relation between activities are defined to analyze the schedule mechanism for a typical floor formwork. Then, worker planning, concrete curing, and form remaining period are investigated. The activity duration is estimated, and the preliminary schedule is accomplished.

2.1 WBS of structural work

Structural work consists of formwork, rebar work, concrete work, mechanical work, and electronic/communication work. The activities under work item are shown in Table 1, and are divided into horizontal/vertical and construction phases. The dividing principle of an activity is as follows:

- If work item is different, the activity is separated.
- If work item is same and production unit are different, the activity is separated.
- Though work item and production unit are same, the activity is not continuous, the activity is separated.

Table 1. WBS of typical structural work

Work	Detail work
Formwork	Inked string work
	Disassembling wall form
	Delivering/assembling wall form
	Disassembling/Assembling Slab form
	Disassembling of stair and core wall form
	Delivering/assembling stair and core wall form
Reinforcement work	Delivering/assembling wall reinforcement
	Delivering/assembling slab reinforcement
Mechanical Electronic / Communication work	Wall mechanical/electronic/communication work
	Slab mechanical/electronic/communication work
Concrete work	Concrete pouring
	Concrete curing and Slab form remaining
Etc	Cleaning/Test/Finish

Fig. 1 shows a typical 12-day structural work schedule, which is developed from the WBS of Table 1.

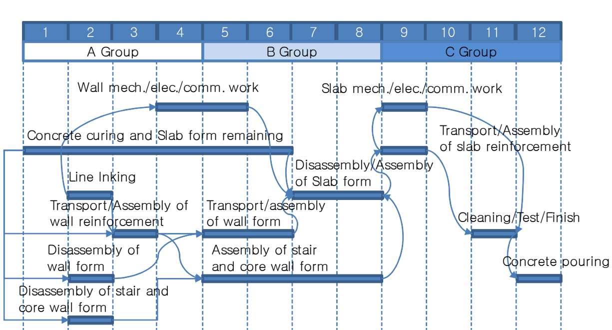

Figure 1. 12 days typical floor structural work schedule

The preliminary work is identified as inked string work. Inked string work begins after completing the below slab. Then, the below slab is followed by the inked string work, concrete curing, and slab form remaining period. However, inked string work can start one day later after concrete pouring, if the inked string work has a one day lag of slab form remaining period.

Wall and stairs/core wall form removal can start one day later after concrete pouring, with all three activities starting simultaneously.

After inked string work is finished, wall rebar delivery/assembling work starts. As written above, the relation of all the activities is set. However, mechanical work and electronic/communication work are similar to each other in method and starting and finishing times, and while there are differences between them, they are tied up to one activity.

2.2 Activity duration

After all the activities and the relation of each activity are defined, activity duration is estimated. Activity duration should be minimized and be considered according to productivity. The conditions of activity duration are as follows:

- All activity is only limited to physical and environmental conditions.
- The minimum duration is one day.
- There is no limitation of delivering workforce, while production unit, which is involved in the same work item, should be delivered repeatedly.

Based on above-mentioned conditions, activity duration is estimated in Table 2.

Table 2. Detail activity duration

Detail activity (Activity)*	Duration
Concrete curing and slab form remaining	6days
Inked string work	1day
Delivering/assembling wall reinforcement	1day
Disassembling wall form	1day
Disassembling stair and core wall form	1day
Wall mechanical/electronic/communication	1day
Delivering/assembling of wall form	2days
Disassembling/assembling Slab form	2days
Delivering/assembling stair and core wall form	4days
Delivering/assembling of slab reinforcement	1(2)day(s)
Slab mechanical/electronic/communication work	1day
Cleaning/test/finish concrete pouring	1day

* Korea Concrete Institute (2003) was applied.

2.3 Duration estimating standards

Construction industries have their standard of duration estimation in making a construction schedule.

(1) S company

Table 3 shows the duration estimating standard of S company, which is a major construction company in Korea.

Table 3. S company's duration estimating case

Division	Duration	
T1 Preparatory work	General area	Good : 1month
		Usual : 1.5month
	Peculiar area	Depending on the situation (islands, regulations and restricted areas, squatters, etc.)
T2 Earthwork and foundation engineering	t1 earthwork	1 underground floor : 1
		2 underground floors : 1.5
	t2 foundation	Pile foundation : 0.5
		Down to 3m : 1 Down to 5m : 1.5
	t3 mat	More than 66,000㎡ of gross floor area : 1.5
		Below than 66,000㎡ of gross floor area : 1
T3 Structural work	t4 understructure	1 underground floor : 0.67
		2 underground floors : 1.33
	t5 superstructure	Under 15 floors (n floors) : 2x0.67+(n-2)x0.45+0.3
		Above 15 floors (n floors) : 2x0.67+13x0.45+(n-15)x0.5+0.3
T4 Finish-work	5 floors below	More than 11 buildings : floor(understructure+superstructure)x1.2
		Less than 10 buildings : floor(understructure+superstructure)x1.0
	10 floors below	More than 66,000㎡ of gross floor area : floor(understructure+superstructure)x0.6
		Less than 66,000㎡ of gross floor area : floor(understructure+superstructure)x0.55
	11 floors below	More than 66,000㎡ of gross floor area : floor(understructure+superstructure)x0.65
		Less than 66,000㎡ of gross floor area : floor(understructure+superstructure)x0.6

(2) Korea Land and Housing Corporation (LH)

According to the study of LH Research Institute (Korea Land and Housing Corporation, 2003), the estimating standard of the structural work is as follows:

Estimating Standard of LH

a) Structural work

- 15 floors below : 1st floor (29 days) + floor number X 12 days (above 2nd floor)
- 16 floors above : construction duration of 15th floor below + floor number x 13 days (above 16th floor)

(Add if steel roof will take 9 days, and if concrete roof will take 13 days)

b) Finishing work

- 15 floors below : 127 days
- 16 floors above : 127days + 1 day/floor (above 16th floor)

(3) L company

Table 4. L company's estimating standard case

	Duration estimating standard	Note
Method 1	·Excavation and foundation work : separate calculations ·Structural work and finish work : 1 month/floor ·Other construction duration : 3 month	Experience
Method 2	·Construction duration : 1.5month/floor	Experience

(4) H company

In the case of H company, construction duration is calculated by working day plus non-working day.

Table 5. Pure working days of structural work by floor

Floor	basement	underground	1st floor	2~4th floor	5~15th floor	16th floor	Above 17th floor	P/H
Number of days	10	22	25	12	10	13	10	24

2.4 Schedule influence factor in structural work

In this chapter, schedule influence factors in structural work are analyzed through a case study.

Table 6. Cases of Apartment construction duration (Structural work)

Corp.	Name of APT	Households	Floors	Total duration	Duration (day/floor)	Note
L	Yeongtong-gu APT	1040	-3/20	28	17.78	Flat-type
	Sanghyeon-ri (suji 2nd)	992	-2/20	29	12.96	Flat-type
	Hwamyeong-dong	1950	-2/23~30	36	11.32	Flat-type
	Hwagok-dong	1164	-2/12~25	33	11.97	Flat-type
	Bisan-dong	965	-2/25	34	13.52	Flat-type
S	Gileum-dong Raemian	1125	8~20	32	13.1	Flat-type
	Jongam-dong Raemian	1168	-3/16~20	37	15.95	Flat-type
	Dangsan-dong Raemian 4th	1391	-2/17~25	37	15.5	Flat-type
	Seocho Raemian (kukdong)	1129	10~27	38	11.08	Flat-type
	Yongin-si Gusung 1st	1282	-2/11~20	32	13.96	Flat-type
D	Trump World	-	-5/41	39	14.5	Tower-type
	Haeundae Trump World	564	-3/30~37	45	11.8	Tower-type
	Sacheon Prugio	998	-1/15	26	12.3	Flat-type
H	Samseong-dong I-Park	-	-3/46	38	11.6	Tower-type
	Jangan-dong Apartment	2182	-2/12~28	41	15.0	Flat-type
	Haeundae Hyperion	266	-4~41	35	8.6	Tower-type

In the case of a common residential project, construction duration in superstructure structural work is about 10~13 days per floor, or approximately 12 days per floor.

The relationship between construction duration and the residential project scale are shown in Table 7. In Table 7, total construction duration is related to the number of households, while structural work duration is strongly related to the number of floors in the superstructure and in the understructure. However, the data did not explain that the construction cycle time per floor is mainly influenced by the structural work itself.

Table 7. Relation between project scale and schedule

		Households	Number of superstructure floor	Number of understructure floor
Duration	Pearson correlation coefficient	0.143	0.498(*)	0.302
	p-value (both side)	0.626	0.05	0.255
	N	14	16	16
Structural work duration	Pearson correlation coefficient	-0.196	0.846(**)	0.849(**)
	p-value (both side)	0.503	0	0
	N	14	16	16
Duration by floor	Pearson correlation coefficient	0.382	-0.405	0.102
	p-value (both side)	0.178	0.12	0.707
	N	14	16	16

** Correlation Coefficients notes level 0.01 (both).

* Correlation Coefficients notes level 0.05 (both).

3. ANALYZING THE CONSTRUCTION METHOD FOR HIGH-RISE STRUCTURAL WORK

3.1 Outside wall form

(1) Gang form

The basic elements of a gang form system include the sheathing (the surface that faces the concrete), studs, wales or walers, stiff backs or strongbacks, angle braces, ties, and safety equipment, including attached walkways and safety rails for workers to use during concrete placement and tie-offs for safety harnesses. Longer sections of gang forms require a spreader beam to easily distribute lifting forces from the crane.

Gang forms can be steel, aluminum, wood, plastic, or some combination of these materials. A wide selection is available from various form manufacturers. The system that you choose will be based on the number of reuses you hope to get, gang form weight, lateral pressures anticipated during concrete placement, cost, and the degree of architectural finish required. Gang forms typically get about 30-40 reuses. A 0.5 reuse per floor is economical over a 15-floor residential project.

(2) Guide-rail system (GRS)

Form plate is the same as gang form, where the form below is fixed by a bolt, while a turn-buckle should be used for ensuring stability. When form is moved by a tower crane, the guide-rail system uses a rail for form moving, which makes it stable with the crane and wind load.

(3) Auto-climbing system (ACS)

The ACS operates as a self-climbing formwork system used for the construction of tall concrete structures, such as building core walls. The ACS provides fast cycle speed, easy operation, excellent construction quality, and the lowest in-place concrete cost in high-rise building construction. Additionally, because ACS includes live load and wind load design, ACS is high in quality and is a safe construction method.

Table 8. Comparison Gang form, GRS and ACS

Division	Gang form system	Guide climbing system	Auto-climbing system
Cost	Cheapest	Cheaper than Self climbing	Expensive
Duration (each floor)	6~12 days Cycle	6 days Cycle	5 days Cycle
Climbing duration(each floor)	1 day	0.5 day (40ea Platform)	1 hour
Crane necessity	Necessary when climbing	Necessary when climbing	Unnecessary (minimize working crane)
Pre-work, post-work when climbing	Much more pre-work, post-work	Much more pre-work, post-work	Less pre-work, post-work
Influence of wind	Absolute influence of wind (getting worse to be high altitude)	Almost never(design criteria: wind speed 45m/sec)	none(design criteria: wind speed 45m/sec)
Possibility of safety-accident when climbing	Very much	None	None
Possibility of form modification	Very much	Almost never	Almost never
winter work	Influence on schedule	None	None
Selection Criteria	Building below 25th floor (considering local condition about coast etc.)	25th~35th floor	Above 35th
Type of purchase	Buy	Almost lease	Almost lease

3.2 System form

System form is used for form works in order to improve the work efficiency of wall and slab form work and to shorten the construction period. There are many products for system form, but aluminum form (AL-Form) and al-wood form (AL-Wood Form) are frequently used in Korea.

They are produced at the factory according to the drawing, and can be easily assembled and dissembled at the site, resulting in shortening of form work duration in a typical floor.

3.3 Other construction methods

(1) Stair construction method

Stair work is also a process that requires time and workforce in structural work. To shorten this process, shop-fabricated stair steel form is used, or PC stair is prefabricated and installed in the site.

(2) Use of CPB equipment

CPB (Concrete Placing Boom) equipment is used for effective distribution of concrete at a high-rise structure or a large area.

(3) Other methods

To shorten the construction duration of structural work, work is conducted by separating horizontal spaces. To simplify the structural work, the location of the wall is adjusted, or PC is installed partially.

4. CASE STUDY

4.1 Case overview

(1) H project

In terms of construction scale, the case involves two (2) buildings in a reinforced concrete structure with 41~42 stories above ground and 4 below. Its total gross floor area is 85,476.75 ㎡. The ACS with fast lifting speed is used on the external wall of the structure of form, and the standardized gang form (aluminum form) is used on the internal part in order to raise the efficiency of the works.

To endure the compressive strength of a high-rise building, high-strength concrete with compressive strength of over 270 kg/㎠ was used (ACI Committee 209, 1992). For the 4 ~2 stories below the ground and the 39 stories above the ground, concrete with compressive strength of over 400 kg/㎠ was used in an earthquake-resistant design. For the stairs, PC stairs are lifted with a tower crane and are then assembled. Only the stair landing is executed along with reinforced concrete work, resulting in the shortening of the number of process days and securing of the quality.

The tower crane was arranged so that the Tip Load would be maximized in consideration of the lifting of the rebar and the gang form, and by reviewing whether or not there is no interference with neighboring high-rise buildings that may delay construction. One unit of a 12-ton T/C per building was planned in consideration of the gang form lifting the work and rebar work period, but the plan was changed to 1 unit of T/C 20 ton due to ACS.

(2) T project

In terms of construction scale, the case focuses on the building in reinforced concrete structure with 30~37 stories above ground and 3 stories below ground. Its total gross floor area is 125,513.59 ㎡ and the height is 119.6 m. For the form, the GRS with a stable T/C lifting was used on the external wall of the structure, while the gang form and the aluminum form were used for the external inner wall and the inside form that was the same as in the H project. The box form was used for the CORE part of the elevator, simplifying and dissembling them than the existing form. At the 4th floor, concrete was poured over the pillar, the 1st and 2nd pillar (a total of 3 times), with an earthquake-resistant design. For stair work, it is shop-fabricated and is only assembled in the site.

4.2 Comparison and analysis of process schedule of T project and H project

The number of process days for the two (2) sites were compared by applying the system classified in Table 9 to the number of working days and work operation system.

Table 9. Structural work type comparison between H and T site

		H site	T site	Note
Form work	Outer wall	ACS (Self climbing)	GRS(Tower Crane)	ACS (advantageous schedule)
	Inside wall	Aluminum system form	Al-wood form box form(core)	Similar
	Stairs	PC stairs	Al-wood, steel prefab form	Similar (PC stars a little advanta-geous)
Reinforc-ing rod assembly	Walls	pre-cutting rein-forcing rod	pre-cutting rein-forcing rod	same
	Slabs	pre-cutting rein-forcing rod	pre-cutting rein-forcing rod	same
Concrete pouring		CPB	CPB	same

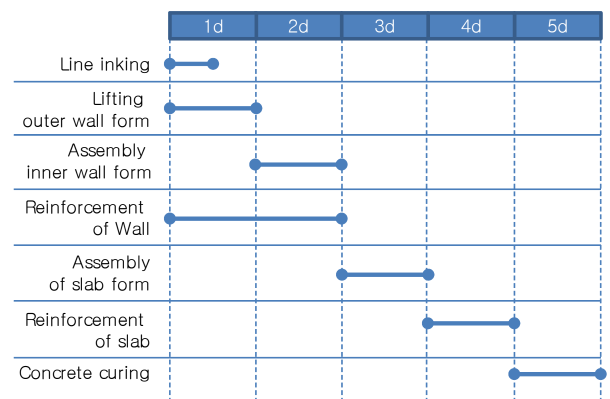

Figure 2. Structural work 5-day cycle

4.2.1 Analysis of the floor cycle time of the T project

(1) Curing/inked string work

Since the restriction on the form remaining period of six (6) days was removed from the high-strength concrete of over 270 kg/㎠ and two (2) sets of slab form, inked string work can be conducted immediately after concrete pouring. Inked string work was performed for 0.5 days, shortening the two (2) processes by 1.5 days compared to the basic process.

(2) Delivery and assembling of wall rebar arrangement, delivery and assembling of wall form and wall electricity/communication/equipment

The basic process becomes a 4-day process: adding wall rebar assembling for one (1) day, wall form for two (2) days, and wall electricity/communication/equipment process with a 1-day delay. In the T project, wall rebar assembling takes two (2) days, including the simultaneous process with the preparation/dissembling/lifting of the external wall form preparation, as shown in Fig. 2. Since electricity / communication/equipment processes are also simultaneous processes, these processes combined to entail 3.5 days, resulting in shortening the process to 0.5 day.

(3) Slab form removal/assembling, delivery

The basic process becomes a 4-day process: adding slab form/dissembling/assembling for two (2) days, and slab rebar delivery/assembly for two (2) days. In the T project, shop-fabricated/fieldassembled ready-made form was used for the stair/core form on the site, so that it is not related to construction. By increasing workforce and pre-assembled rebar and closing the slab electricity/communication/equipment at the same time, the period of slab form work was shortened to 1.5 days and slab rebar arrangement to one (1) day.

Since cleaning inspection/finishing was not included in the calculation of the number of main process days, but included the slab rebar arrangement process, the main process was shortened by one (1) day. Fig. 2 shows that 0.5 day was shortened from the main process by performing inked string work and wall rebar work at the same time. As a result, the process plan lasting a total of seven (7) days was obtained from the T project by combining one (1) day of concrete pouring.

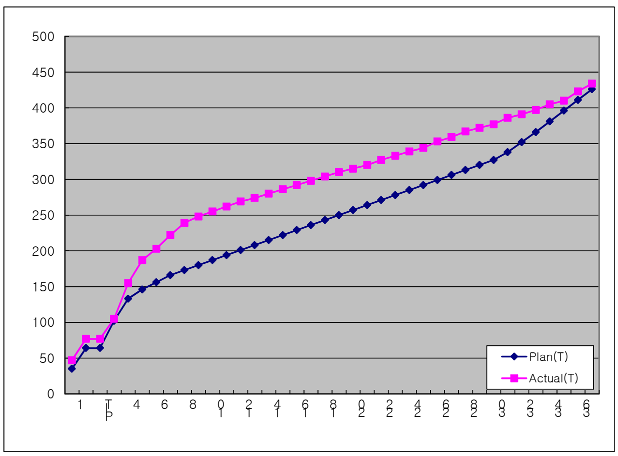

Figure 3. Schedule performance of case T

4.2.2 Analysis of the floor cycle time of the H project

In the H project, the process was shortened to five (5) days by using the shortening construction method of the H project from the T project. Since the shortening factor of the H project overlapped with the analysis of the number of shortened days in the T plan process, the H project was analyzed by focusing on the shortening factor in reference to Fig. 2 based on the T project.

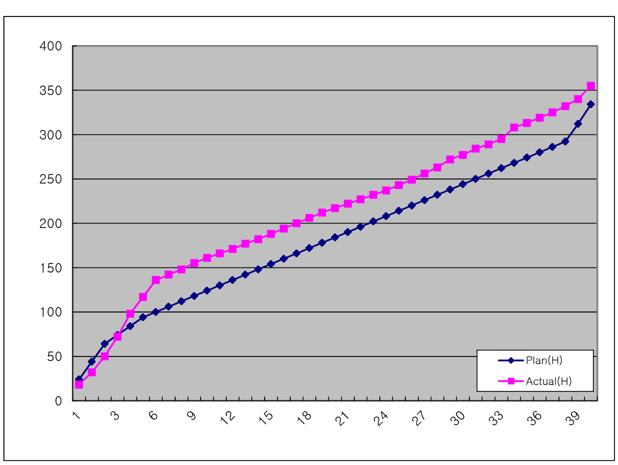

Figure 4. Schedule performance of case H

(1) Lifting of external wall/internal wall form, wall rebar arrangement

ACS was used for the external wall form in the H project so that it could be started simultaneously with inked string work without preparation for lifting due to self-lifting rather than crane lifting of GRS in the T project, resulting in shortening the process for 0.5 days. Furthermore, lifting speed was planned 0.5 days faster than the GRS (T project) due to the ACS feature. Wall rebar work was conducted along with external form work so that wall form work could start immediately, shortening overall wall work for 1.5 days.

(2) Slab form

The process was reduced by using the ready-made form for stair work in the T project, but 0.5 days were shortened more in the H project by using the PC stair construction method. Since electricity/equipment is conducted simultaneously with form, it was found not to affect the total number of days it took to complete the process.

Fig. 5.6 shows the plan process that was analyzed by correcting the number of non-working days in Table 10 to process the work in the H project and in the T project, which is, 5 days and 7 days of processing day per floor, respectively.

Table 10. Non-working days planning

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum
2003	1	2	4	10	7	5	16	11	5	0	6	1	68
2002	3	1	4	5	4	3	9	11	3	5	1	4	53
2001	4	2	0	3	4	5	7	6	4	3	1	1	40
2000	1	0	5	3	5	4	6	8	5	2	3	0	42
1999	2	2	6	2	7	7	5	10	8	4	0	0	53
1998	3	6	4	8	7	10	8	11	2	4	2	0	65
1997	1	2	3	5	6	6	8	8	3	0	5	2	49
Avrage	2.14	2.14	3.71	5.14	5.71	5.71	8.43	9.29	4.29	2.57	2.57	1.14	52.86

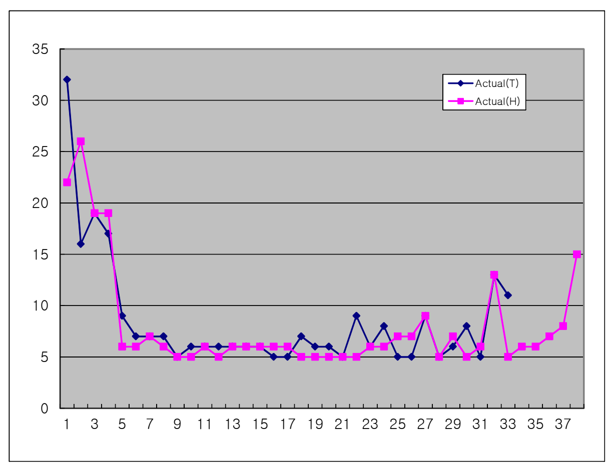

Figure 5. Schedule performance of H site and T site

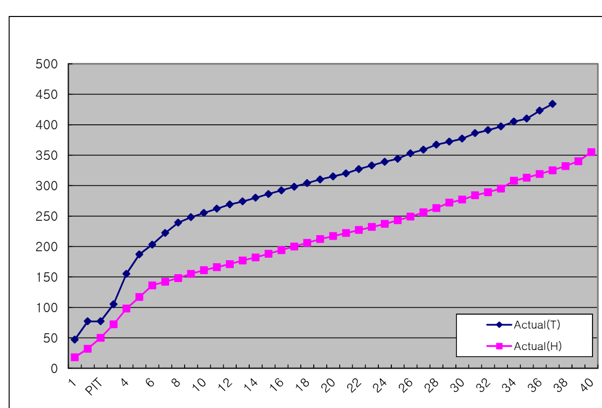

Figure 6. Cumulative schedule performance of H site and T site

In Fig. 5 in which the process plans were compared, it was found out that it took nine (9) days from the 11th floor to the 29th floor in the T project, and six (6) days in the H project. Based on the difference in speed at the H project and the T project in Fig. 6, the difference in the number of work days of the overall work duration started with 22 days at the 10th floor, and began to increase and reached 136 days at the 49th floor. From this result, it is known that work progress speed becomes faster in the H project than in the T project over time.

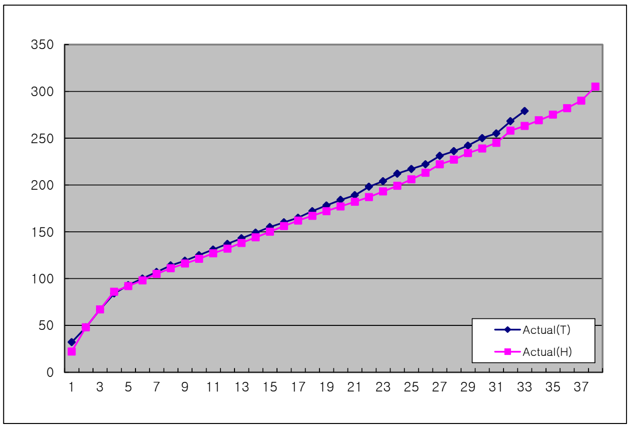

Figure 7. Schedule performance comparison(typical floor)

4.3 Comparison of the number of process days among actual ASC, GRS, and gang form

While they were compared with the process plans of each project above, the H project (ACS), the T project (GRS), and the P project (gang form) were compared, as shown in Fig. 8 and Fig. 9, in order to analyze the factors in work duration change due to the form factor in actual work.

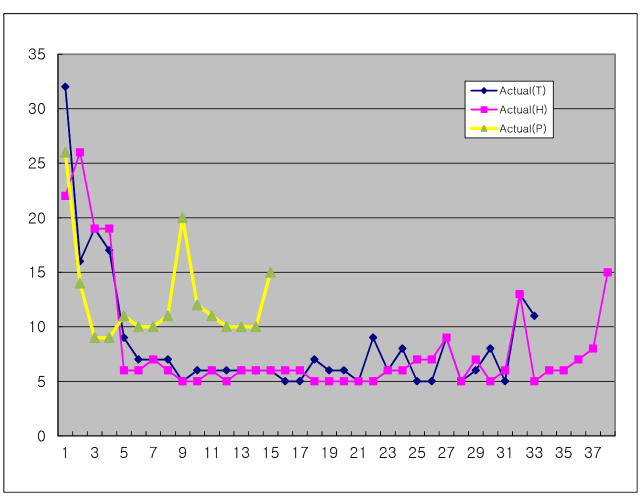

Figure 8. Duration comparison of H, T and P site

Fig. 8 shows that work was faster in the H project due to form setting on the 3rd and 4th floor and initial lifting work. However, when comparing the number of each process day at the typical floor (5th floor ~ 38th floor) in the H project and the T project, as shown in Fig. 9, the H project records 6.6 days per floor, while the T project records 7.2 days per floor, meaning that the H project was proceeding faster by 0.6 days per floor. While proficiency does not affect the schedule since ACS is lifted due to the control of the overall mechanical system after setting is finished at the 3rd and 4th floors, GRS is lifted with a crane so that proficiency in lifting preparation will affect the process. It is analyzed that a difference might occur up to the 7th floor in the H project and in the T project, but there was almost no difference found in construction duration after that floor.

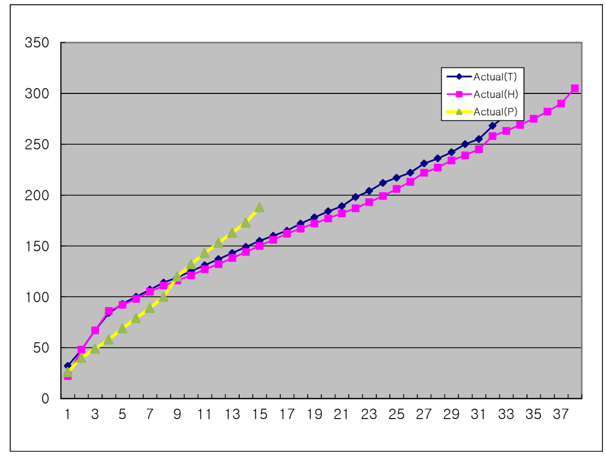

Figure 9. Cumulative duration comparison

The P project records an average of 10.8 days per floor, and slope is constant. Fig. 9 shows that it intersects with that of the H project at the 15th floor, and with that of the T project at the 21st floor. As a result, the H project (ACS) was found to be more effective than gang form at stories above the 15th floor, and in the T project (GRS) at stories above the 21st floor.

4.4 Simulation of working days in high-rise structural work

Simulation can be used to estimate the duration of structural work in future projects. We used the Monte-Carlo simulation method to estimate structural working duration in this paper. The total duration of structural work can be calculated with the following formula.

Time (Structural work) = Time (Form setting) + Time (Typical floor) + Time (Penthouse)

The distribution of structural work duration of a typical floor and lower floors are as follows:

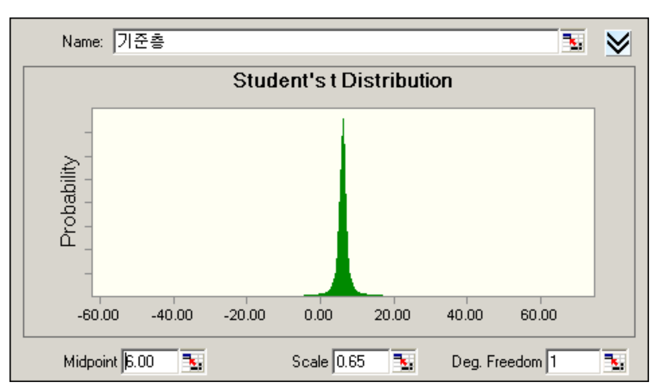

Figure 10. Distribution of 1 floor structural work cycle

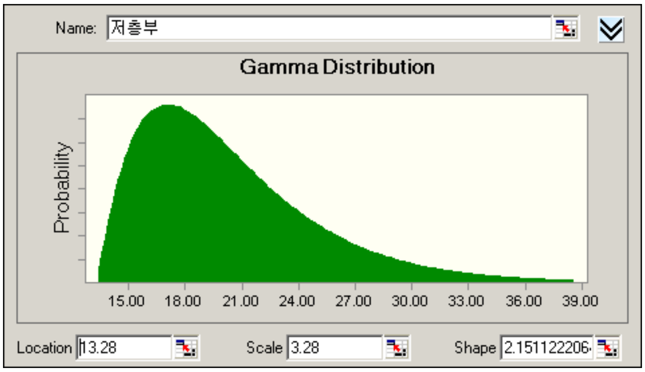

Figure 11. Distribution of system form setting duration

With this distribution, the result of the Monte-Carlo simulation is as follows on Fig. 12 and Table 11. With this result, we can find that the error rate of the duration estimation is below 5%, and this method can be used to planning a similar project.

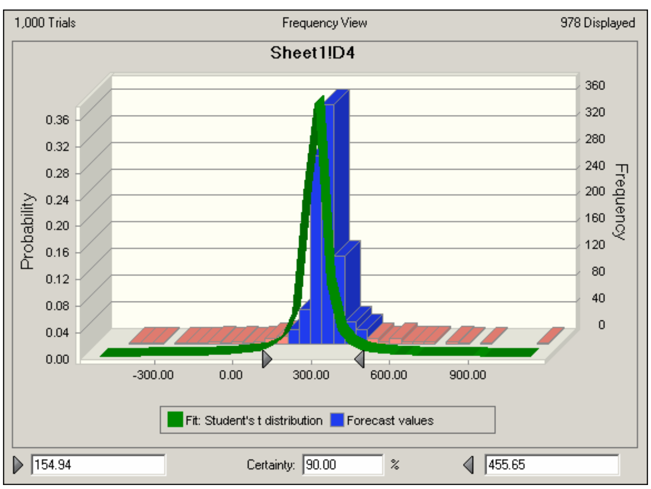

Figure 12. Result of duration simulation of 39th floor case

Table 11. Analysis of simulation result

	Result(days)	Note
Initial planning schedule	290	Form setting : 20days*4floors Typical floor : 6days*35floors
Actual schedule	305	error rate 4.91%
Simulation	297.38(average)	error rate 2.6%

5. CONCLUSION

Land price and lifestyle have created high-rise residential projects with increased construction duration and difficulty. In a high-rise residential project, framework is the most time-consuming, therefore, a construction company must focus on reducing construction duration. Framework consists of inked string work, delivery and assembling of rebar arrangement, form removal and assembling, and concrete curing. Among those composite works in framework, this research was performed by considering two aspects: shortening construction duration and feasibility in formwork. Gang form is effectively used in buildings with less than 15 floors. However, in buildings with more than 15 floors, it is not suitable due to wind and stability. This research focused on ACS and GRS of a residential project with over 15 floors.

This study suggested Equation 3) based on data on effectiveness. According to Equation 3), the longer the construction duration, the lesser is the cost of ACS. It means that in high-rise structures, ACS is more effective than GRS.

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